Paper

Context awareness and nomadic devices featuring advanced information visualization in clinical routine

Athanasios M. Demiris and Nicolaos Ioannidis

Abstract— The demand for ubiquitous and efficient information delivery is increasing rapidly, as the majority of access to professional data, information and knowledge is increasingly relying on the use of technology. Mobile workers become more efficient, if equipped with access means similarly powerful to stationary workplaces. All types of work exhibiting inherently nomadic characteristics are even more affected by these developments. Healthcare personnel in a clinical environment are definitely one of the typical examples, where the access of information is vital and bound to location. Additionally the information needs to be processed in very short periods of time. For this purpose it is of great advantage to deploy advanced information visualization technologies in order to communicate larger amounts of data in a shorter period of time. In this work, we present an IT platform, which emerged from applications in the cultural heritage domain, that can be used to deliver context-aware services and advanced visualization of information to medical personnel in a clinical environment. The location combined with usage profiles for each member of the stuff are used to make the decision about the type and amount of information as well as the visualization type delivered to the handheld devices. Along with the description of the platform and its components, two application examples/medical use cases are presented.

Keywords— context aware services, healthcare support, ubiquitous computing, information visualization, nomadic devices, service platforms.

1. Introduction

Numerous applications in the past decade deploy handheld devices, such as personal digital assistants. The initial versions of this ultra-mobile computers, were aiming at a segment of the consumer market, where more expensive digital tools are often used as support of daily work. In a second stage of maturity, when the processing power of such devices grew to resemble PC processing, peripheral devices were integrated into the portable digital assistants (PDAs), their application domains expanded from simple office support to all possible areas. The mobility of these devices led to the term nomadic, indicating the ability of their users to change places without losing their access to basic e-mail connectivity and some additional business-oriented functionality.

One of the most obvious application domains, since the first days of nomadic devices, were so called multimedia guides for cultural heritage sites. Enhancing their predecessors, acoustic guides, multimedia devices started appearing in exhibitions, museums and archaeological sites, providing an easy to access pool of audiovisual information to visitors. They provide major advantages over existing acoustic guides and booklets related to sites, such as the attractiveness of the presentation and the richness of the expression means for the museum curators that offer a significant competitive advantage to cultural heritage institutions.

We have been developing solutions for mobile devices in cultural heritage institutions for a series of years and in a variety of versions, as presented in [1, 2], featuring more expensive high-end solutions as well as inexpensive, simple multimedia guides. The basic system for the creation and valorisation of content, as well as the infrastructure necessary to support the deployment of such systems in daily routine, may have been developed based on experiences gained in the cultural heritage domain, but they may easily be adapted to any other domain, where the application of such nomadic devices would provide a solution to the easy and fast access to information (mostly in audiovisual formats). Such an application domain are intra-hospital information management systems.

In our case we present a platform for context aware services on nomadic devices that is easily attached to the central hospital information system (HIS), or in the case where such a system is not present, some of its functionality may be taken over by the platform itself. The system may be used by different users within a clinical environment serving different purposes. The initial version of such a system is aiming at delivering information to medical personnel, i.e., mainly physicians, while they are visiting their patients. The medical record of these patients may be retrieved instantly, while the physician approaches the bed of the patient.

The same device may be used for communication purposes of different types. A typical application scenario is the notification of the medical practitioner by the ward personnel about an important call or appointment, etc. Additionally two physicians may communicate with each other consulting on a specific case, e.g., the surgeon visiting a patient performs a quick dialup of the radiologist in order to ask for some clarifications related to the imagery found in the retrieved patient record. Finally when a physician visits a patient followed by trainees, they are capable of "locking" the screens of their devices to the screen of the physician, in order to follow the processing of the case, as conducted by the teaching physician. Hence they learn what type of infor-

mation is retrieved by the experienced personnel, in what order, etc.

Context aware services in a clinical environment may also serve the purpose of optimizing the workflow of nursing personnel. When entering a room, the scheduled tasks for all patients found in the room are presented in a task list. Each task completed is then checked and removed from the list with a concrete time-stamp, which might help them to capture the exact sequence of medical acts on every patient upon request.

Context aware systems may come as a natural extension of any information management infrastructure and help communicate the information to the interested practitioners in the right time and place. Especially in the clinical environment the introduction of such systems may result in a significant improvement of clinical workflow. In our contribution we will be demonstrating the architecture of the system as well as two sample use cases in clinical environments, which significantly enhance and correct all shortcomings of current workflow.

2. State of the art in context aware services and related medical applications

Context aware computing is an emerging field, where most of the attempts thus far where directed towards the solution of basic problems. Nevertheless, there are already some systems appearing in everyday use. One example, which happens to be the outcome of a European research activity, is presented in [3]. The main goal and the major difference to our approach, is the creation of generic framework for context aware services on the client platform with the focus on the handling of various sensor inputs, as well as the linking of these sensors to events. In our case, we very much focus on the back-office infrastructure to support and publish context-aware services, while on the client side we assume a reduced set of sensors (the wireless LAN positioning and additional sensors for increased accuracy in the location detection, such as radio-frequency (RF) tags and/or infrared sensors).

Applications of mobile computing in medicine are focusing mainly on patient monitoring and decision support. Hence in [4] the notion of pervasive healthcare is introduced focusing mainly on the pervasive monitoring of the health situation of a patient. A similar work related to wearable sensors is presented in [5].

A work presenting scenarios very similar to the ones in our work can be found in [6]. The authors introduce the idea of the context-aware pill-container, a device that helps avoid errors in drug administration, and the context aware bed, which uses the same resources (such as a built-in display) in a different way for different users, e.g., in order to display the electronic patient record (EPR) to the medical personnel or a TV station to the patient. The work presented in [6] is purely conceptual and in a series of workshops, with the participation of healthcare professionals, the integration of such context aware devices in clinical routine was investigated and judged a driving factor for further improvement in the clinical routine.

A solid theoretical framework for the modelling of context-aware services in a clinical environment is presented in [7]. The authors introduce the means for contextual modelling of processes and demonstrate the usage on the basis of medicine administration. The process of evaluating the overall idea is the same as in [6], namely user workshops, something that is related to the fact, that the authors originate from the same institution.

In [8] the use of personal digital assistants is described in the context of medical education and practice. Although an aspect, which is of interest to our solution, it is definitely not the focus of the platform we are describing in the present work, since our focus is the daily clinical routine. Both cases are extremely interesting and there are definitely many common aspects mainly in the choice of platforms. Nevertheless, our approach is clearly aiming at the support of clinicians and their nomadic work behaviour.

In [9] the notion of collaborative systems is introduced in the medical context and the resulting advantages are discussed. The main focus of this work is in communications across the boundaries of hospitals and collaboration is interpreted mainly in the sense of tele-medical applications. In our case, we are presenting a system that is aiming at the support of clinicians within one hospital, while the communication with other practitioners outside the boundaries of their hospital are possible, but not the primary goal.

In [10] a very good analysis of the nomadic character of the clinical routine is introduced. In this approach presented by Bharadwaj *et al.* mobile devices are also deployed within the clinical environment and there are clear similarities with the approach presented here. The focus of the work by Bharadwaj *et al.* is the communication and exchange of information between clinicians and insurance companies for the benefit of the patients. A dedicated XML communication language is introduced for this purpose.

An application of mobile technologies can be found in [11]. In this work the main focus lies in the use of mobile technologies in clinical trials for the increase of accuracy and confidence in the results, as well as decrease of the time-to-market. Such efforts may be considered complementary to the work presented here, covering a different need.

3. The architecture of the intGuide platform

The intGuide provides the means for creating, managing and publishing multimedia content that is location-specific on various platforms, ranging from portable digital assistants to high-end mobile phones. For this purpose

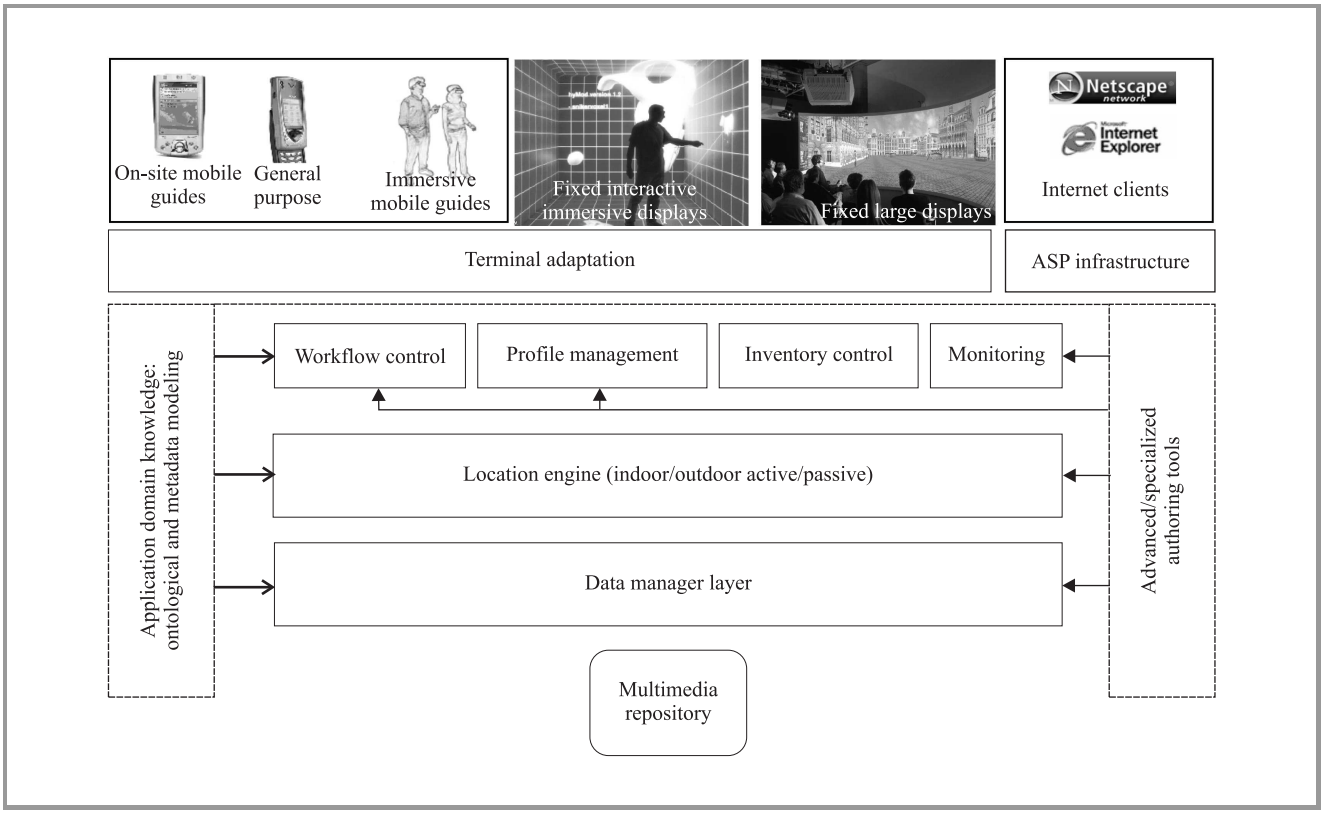

Fig. 1. An abstract schema of the layered architecture of the intGuide platform.

the intGuide platform unites a set of software tools necessary to:

- characterize, i.e., annotate, position in space and generally manage digital assets;
- combine various multimedia files to grouped presentation units;
- visualize information in an advanced manner, mainly by means of augmented reality;
- connect to other repositories to retrieve information, provided their structure is known to the system;
- publish the content on a rich variety of client device types;
- manage the inventory of hardware devices;
- monitor the operation of all devices attached to the central server, allow for their communication and collect, as well as present statistics.

The core of the back-office system is a specialized database management system, adapted to host multimedia data of different types. Moving towards the upper part of the Fig. 1 the functionality moves closer to the end user. In the upper layer, a set of supported client platforms is presented.

4. The usage of the intGuide platform in a clinical environment

We consider intGuide in a clinical environment as a supplementary infrastructure system, which extends the existing electronic patient management system (be it at ward, clinic or hospital level) introducing complementary functionality, which allows the information to become ubiquitously accessible.

Location and context awareness are features that have proven to significantly enhance the daily work situation of most nomadic users, such as the medical personnel in a hospital environment [10], but are not provided by any of the existing IT systems. The reason for that is that current information technology infrastructure systems are developed based on the hypothesis of information accessing by means of fixed terminals. The only differentiation is the one of roles within the hierarchy of the healthcare organization, or the responsibilities in healthcare provisioning, i.e., different access to the information for medical doctors and different to administrative personnel.

The introduction of such systems does not only restrict their usage to the information access, but may be extended to a set of other functions, which may enhance the work situation. An often encountered problem in the everyday life of nomadic users is the communication between them. An infrastructure that delivers location and context aware services may very well also use this information to

establish communication links between different participants and transmit voice signals from one device to the other or multicast/broadcast information. The intGuide is featuring a voice and text communication model, allowing for the peer-to-peer exchange of information or the centralized multicasting of multimedia messages.

5. Content authoring

Using dedicated intGuide authoring tools, it is possible to enter all types of digital content and annotate it. The schema according to which this annotation takes place follows well known international standards for each application domain. In case a standard is not missing, or a potential user of the system is not interested in using a standard annotation but prefers to use a proprietary schema, it is possible to introduce a new definition. The reason for that is that the intGuide repository is hosting in its very core mainly multimedia related characteristics, while the rest of the documentation is kept in dedicated tables, which can be handled dynamically by the data manager. This is the major advantage of the content management system found in the core of the intGuide architecture.

The authoring tools rely on a dynamic template concept to allow grouping of the content in a way that allows for easier access of the users. An example in the medical domain could be the templates for different disciplines or different clinics, even different medical doctors. In such a template the head of the clinic can declare all types of information that are necessary to be displayed in a screen on a device. The system will use this template to dynamically load all information related to one patient at runtime. The system allows theoretically to introduce an arbitrary number of templates, hence it is possible to define a template for different types of diseases, even for every patient. Nevertheless such a practice is time consuming and reduces the efficiency of medical personnel, since they need to carry out a much more thorough documentation in order for the templates to be correctly identifiable.

6. Inventory control

The introduction of portable devices in a clinical environment is not straight-forward and needs very careful planning and administrative support to have a positive impact on the actual work carried out, as proven in numerous other domains. Taking into consideration that portable digital assistants are devices for personal office use focusing on simple business tasks (such as calendar functionality, contacts, simple voice memos, etc.), it is obvious that any other more demanding use needs to be planned carefully prior to being introduced in a daily routine.

Within intGuide there are tools addressing the administrative issues related to the use of mobile clients. Hence there is an inventory control unit, keeping track of the devices available, their characteristics, as well as statistics concerning their performance and usage. There is a dedicated registration-deregistration component that can be used when handing out the devices to the personnel and when collecting them at the end of their work (if such a model is selected for a hospital). Additionally the inventory control is featuring an online component, which allows for the monitoring of all devices and their parameters, such as their current location, their current battery status and any possible alerts that are related to their smooth operation. Hence if the battery level of a device is reaching a limit, the personnel responsible for the monitoring may bring an alternative device or backup battery to the user, e.g., medical doctor and thus support them without having them interrupt the operation.

Support of collaborative work. The portable devices may be used also as the ambient memory of the hospital. An important aspect in clinical workflow are appointments and scheduling. A centralized calendar, which is capable of holding the appointments of all personnel may be used to issue reminders in due time. The scheduling of the appointment can thus take place as the need for such an appointment occurs and can be transferred immediately to the account of the member of the staff and all other involved entities, so as to have it available during their work in their stationary workplaces, too.

Fig. 2. Current portable devices come in compact rugged cases and feature build-in wireless LAN connectivity.

In addition to the relatively static exchange of information based on appointment scheduling, another important feature, which increases significantly the advantages of the use of mobile devices within the clinical environment is the use as mobile phones (Fig. 2). Push-to-talk functionality after the selection of one or more addressees/participants allows medical personnel to communicate instantly within the hospital without any costs at all. There is no need for beeper devices and the installation of fixed line telephone lines for

internal communication becomes obsolete. The communication possibilities offered by the new technology may even extend to the introduction of "bridges" to the external phone lines, thus redirecting the normal incoming voice traffic to the mobile devices. The latter requires nevertheless phone centres of a more recent generation, which will allow the forwarding of the voice calls along with some additional information, such as caller identification. The latter functionality will allow for a better screening of incoming calls by the medical personnel during work time.

Finally intGuide allows also for a different type of collaboration, namely education of medical trainees. The intGuide features client-side software, which allows for a mobile device to "couple" its display with another display and follow the interactions and information display on this "master" device. This is especially helpful during patient visits in the ward, when a senior medical doctor is joined by a group of younger interns. When approaching the bed of the patient the screens of the mobile devices of the interns may offer the possibility to display the content of the mobile device of the senior doctor and thus follow his/her decisions and information selection, while he/she explains why he follows the steps displayed. The current implementation allows for a relatively large number of clients to connect to a master device, hence enabling a smooth collaborative educational session in the clinical environment.

7. Security aspects

Currently most of the portable computers, PDAs and very recently also mobile phones are equipped with wireless LAN capabilities, thus making it easy for people to enter a wireless network and start using it. The intGuide platform introduces protective measures at various levels, starting with the obvious configuration (upon request) of all involved access points to accept traffic only from designated devices. For this reason the only restriction is the use of wireless access points that allow for configuration of allowed MAC addresses (nowadays a feature of the majority of access points in the market). Additionally the encryption of the data transmitted and the decryption on the viewing terminal is something easily incorporated into the intGuide platform. Finally the access to the content has to pass two levels of authorization, one of them being related to the database users and the other being granted by the profile of the user themselves. Hence although the rights of a medical doctor would normally allow him to access specific data in the database, within a given profile/template (a profile for the radiology specialist, when visiting the ward), might deactivate these access rights.

On the client side there are many ways to secure the access to the information. When a terminal has been idle for a given period of time, it is locked, while a warning/indication is transmitted to the centralized monitoring unit. The latter may be used in cases where the user of the mobile device has accidentally left the device somewhere unattended.

As far as the anti-theft security for the mobile devices is concerned, the intGuide clients always configure the devices to restrict the uncontrolled powering down. In a preferred mode of operation the devices are returned to their charging areas and then they may be switched off. Following this operation mode, it is possible to continuously keep track of the position of the mobile devices and issue an alarm when the mobile device is about to leave the permitted area. This feature may be deactivated. In such a case an alternative approach, such as RF tags on the mobile devices and RF reader installations in doors and windows could replace the security features mentioned before. In any case, there may be devices that certain members of the personnel will be allowed to take outside the permitted area. The suggested procedure in this case is to attend a deregistration station (e.g., at the entrance) and use a mode introduced for this purpose, namely "deregistration for exit". Upon return the device is registered again normally.

8. Necessary infrastructure

The major advantage of the intGuide solution is that it can be considered as an extension to existing information systems (Fig. 3). Hence it may complement existing infrastructure to offer the ubiquitous services within the hospital environment. Some additional components may even be assumed in nowadays implementations of information technology support in modern hospitals, such as the existence of a wireless local area network. The intGuide is a scalable, freely configurable platform and can thus be easily adapted to different situations and varying needs of end users.

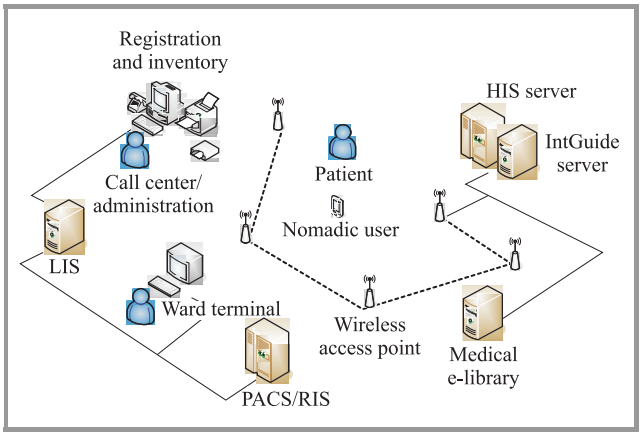

Fig. 3. The intGuide platform complements the existing infrastructure in the clinical environment in order to allow for context aware services in the clinical routine.

The intGuide platform is comprised of the following software and hardware components:

- wireless network, fully compliant with the IEEE802.11n standard – repositioning the access points within the space may be necessary in order to achieve higher accuracy in the WLAN detection;

- optional tags for increased accuracy in the location detection (e.g., RF tags or infrared LEDs);
- a central processing unit (see below), hosting the following software components:
  - WLAN positioning engine,
  - intGuide inventory software suite,
  - live monitoring software suite, featuring scheduling and communication control units,
  - software bridge to existing EPR,
  - authoring tools for the preparation of dedicated presentation profiles and templates,
  - software bridge to scheduling system,
  - registration and deregistration software,
  - a database management system or access to an existing one;
- portable devices, preferably portable digital assistants operating under Windows CE equipped with WLAN functionality, protected by a rugged case and featuring the following software:
  - communication and resource control unit,
  - WLAN positioning client,
  - position detection component,
  - playback control module,
  - synchronization unit,
  - voice communication module,
  - screen locking software (both server and client versions).

The system may operate with one single state-of-the-art PC. Nevertheless this is a solution that is not recommended. It is advisable to introduce a dedicated failsafe server, e.g., a cluster. The software systems may be operated on any terminal equipped with network access and conventional browsers. In the current implementation of intGuide, the authoring tools are dedicated software units that need to be installed on each terminal to be used. In future releases the authoring software will feature also a web-based access interface.

In case the system is configured to operate with increased location detection accuracy, i.e., with additional tags in the space such as RF tags, it is necessary to use a reader device within the mobile devices.

Advanced information visualization. One of the older yet only recently appreciated fields of research in information technology is information architecture and visualization. It is about communicating information in a visual manner and thus allowing for a faster and more efficient comprehension. Even very simple examples make it clear, that information visualization may increase the perceptual value of information and decrease the so called cognitive workload (Fig. 4). Especially in application domains such as medicine in the clinical routine, it is necessary to be able to perceive vast amounts of information within short periods of time, in order to reach fast and accurate decisions.

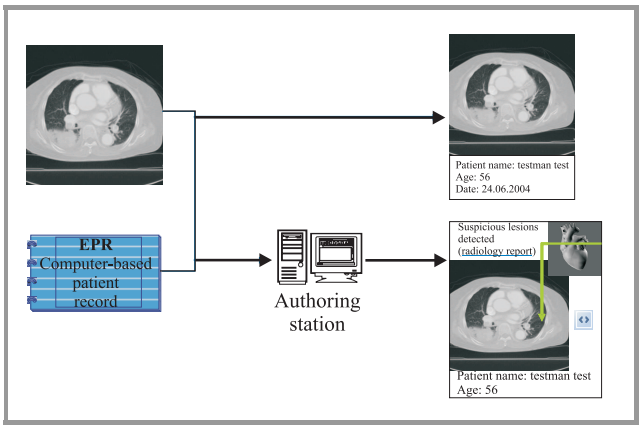

Fig. 4. Simple display of collected data related to a patient in the upper part, authoring tools for advanced visualization enhance the readability of the iamge in the lower part and visualize important information at a glance (light arrow line indicates both the position of the slice in the heart volume and highlights an area to more thoroughly investigate).

The intGuide is supporting possibilities of displaying multimedia information on mobile devices in a comprehensive manner. For this purpose it is necessary to use the corresponding authoring tools. The authoring of content may be time consuming and needs to be carried out by the respective specialist. An example can be medical images: the authoring tools may be used to annotate these images both graphically and textually. These annotations may be classified according to the intended audience, hence some of them will be presented on the devices of surgeons and different ones will be presented on the devices of anaesthesiologists.

The authoring tools of the intGuide platforms have not been developed especially for the medical domain. The modular way of development allows for the extension of the authoring tools by domain-oriented tools, such as visualization and rendering software for radiological departments, or laboratory results, etc. Nevertheless intGuide is capable of handling augmented reality information. It allows for the storage of 3-dimensional models and their matching against actual pictures of the real environment of the users. Hence, assuming that a different (embedded or not) tool is used for the creation of 3-dimensional views of medical information, it is possible to use the authoring environment to match these views against images found in the multimedia database of the system.

9. Application Scenario 1: medical visit in the ward

In order to better present the smooth integration of the intGuide features into everyday clinical routine, two simple examples are presented and the use of mobile devices with the intGuide features are highlighted.

In the first use case, we assume the visit of a patient in his/her room by a senior medical doctor along with three interns. Each physician is carrying a mobile device, which they have gotten at the collection point of their ward. The devices were handed out by a nurse in the ward, who registered the devices to the physicians in her terminal. The terminal is a simple PC connected to the intranet of the hospital, equipped with only a web-browser.

The senior physician approaches the bed of the patient, which features an RF tag in a hidden position. The doctor is provided automatically with a list of information items available for this patient. The information is structure according to a template, that this doctor has selected some time ago and found most useful. The senior physician selects additional information to be retrieved, such as the EPR, the fiver curves of the past days, etc.

The assistants "lock" their devices to the device of the senior physician and follow the actions. In order to do that they initiated a client session by selecting the "follow a collaborative session" option and highlighting the name of the senior physician. The senior physician sees the requests on his screen and allows the presentation of his device on the devices shown in a list by tapping the "allow" button. The session begins and the physician asks questions and then carries out actions using his device.

Suddenly an incoming request for tele-consultation is received by the senior physician only and is not displayed on the screens of the other devices. The physician taps on the graphical indication on his screen and checks the severity of the request by reading a brief description, the name of the initiators and the patient involved. He decides that the tele-consultation may be postponed for after the current visit and replies to the request by scheduling this activity for 15 minutes later. The initiator receives an indication on their screen, accept the postponed session and the rendezvous is registered centrally in the scheduling unit.

10. Application Scenario 2: nursing activities in the night time

The nurse is entering a room in her ward at night time, after she has been reminded by an alarming sound on her mobile device. The centralized system, which is constantly monitoring the schedules of all personnel has initiated this remote reminder. The device displays a list of tasks that need to be taken care of during this time in this room in a suggested order, immediately upon entrance of the nurse in the room. The nurse takes care of each task and indicates their completion by checking a box on her screen besides the task name. A high-level control of the validity of her actions is possible thanks to the location estimation component, which checks for the position of the nurse in the room and related to each of the patients. Hence it would not allow the checking and completion of a task related to patient B, if the reading of the position of the nurse is indicating her being at the bed of patient A. The processing of the tasks are captured by the workflow system and may be propagated to other HIS components (if configured to do so), thus allowing for a more accurate accounting.

Suddenly the nurse realizes that one of the patients needs immediate attention by a medical doctor. She activates the list of available doctors and selects the name of the one available in the hospital with the necessary specialty. She immediately rings him up and starts talking to him about the situation. The medical doctor starts walking towards the ward while talking on his device with the nurse and giving her instructions for immediate actions, until he has reached the room of the patient.

11. Conclusions and future work

It was discussed that hospital personnel exhibit nomadic work behaviour. Hence ubiquitous and uninterrupted access to existing information is a means for enhancing their work situation. Advanced information visualization is the means for effectively presenting information to the user. Context aware systems, featuring advanced information visualization may successfully address many shortcomings of the current routing of nomadic users in a clinical environment. We have presented a system, which was introduced in the domain of cultural heritage and is generic enough to be applied in the clinical routine supporting mobile devices for medical staff. We have presented a set of functions supported by the platform intGuide, as well as indicative use cases, showing the added value for the clinical environment emerging from the introduction of such a system.

A necessary prerequisite for the successful introduction of such a system is the interoperability with existing legacy systems in the clinical environment. Health level 7 (HL7) is one of the things that come to mind in this context. The HL7 information exchange is thus far not supported by the system. If the system is to be introduced as a successful extension to existing legacy systems and not an island solution, HL7 is one of the major priorities of the adaptation to the clinical routine. The main focus will be the connectivity to the EPR system.

Additional helpful features may occur by extending the workflow control system to cover for additional activities. One example in this direction is the monitoring of progress of registered activities, e.g., status of laboratory tests for

individual patients. Other examples of important extension are the accessing of an e-library of the hospital or even an extranet of health.

Acknowledgements

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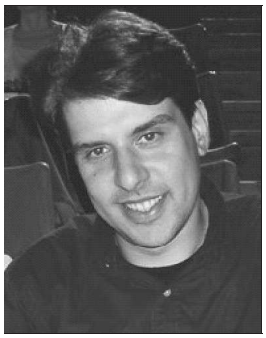

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